

MAPPING AND MONITORING NOXIOUS WEEDS USING REMOTE SENSING

**Vicky Varner and Henry Lachowski
Remote Sensing Applications Center
USDA Forest Service
Salt Lake City, Utah 84119**

**Leonard Lake and Bruce Anderson
Nez Perce National Forest
USDA Forest Service
Grangeville, Idaho 83530**

ABSTRACT

The noxious weed problem is on the increase throughout the United States. Current ground-based surveys require a significant commitment of manpower and money to cover a relatively small area and provide limited information on the extent and spread of noxious weeds. The Nez Perce National Forest and the Remote Sensing Applications Center (RSAC) examined the feasibility of detecting and mapping noxious weeds using various types of aerial remote sensing data acquired with a color infrared (CIR) digital camera, a multispectral camera, and conventional cameras (70-mm and 35-mm). Four noxious weeds—yellow starthistle, spotted knapweed, rush skeletonweed, and leafy spurge—with significant, isolated populations near the Frank Church River of No Return Wilderness in central Idaho were selected for this project. The aerial data were collected in late July. The best results were obtained for leafy spurge, which was visible on each type of the aerial data. Gray, standing dead plant stems indicative of habitat infested with yellow starthistle or spotted knapweed were most evident on the 70-mm photography. Rush skeletonweed was not discernible on any of the aerial imagery. Timing of the aerial data acquisition was the most critical factor for discriminating the noxious weeds from surrounding cover.

INTRODUCTION

The invasion and spread of noxious weeds has become an ever increasing problem throughout the United States. A common characteristic of noxious weeds is their aggressive, competitive behavior. They often become established in soil disturbed by construction, recreation, or fire and are then transported by wildlife, water, wind, vehicles, and people to new sites. Once established, noxious weeds are able to invade adjacent, undisturbed native plant communities where they are typically a poor replacement as a resource value to the ecosystem.

Current ground-based surveys require a significant commitment of manpower and money to cover a relatively small percentage of ground. The results are slow detection and limited information on the extent and spread of noxious weeds. When caught early, an infestation can be contained and even eradicated by methods like hand pulling and/or chemical treatment. Larger, established infestations are much harder to contain and almost impossible to eradicate.

The Nez Perce National Forest and the Remote Sensing Applications Center (RSAC) examined the feasibility of early detection and mapping of noxious weeds using various types of remote sensing data acquired with a color infrared (CIR) digital camera, a multispectral camera, and conventional 70-mm and 35-mm cameras mounted in an aircraft. Early detection has a more stringent standard than mapping. It demands that at least 95 percent of the small infestations be located and allows a proactive weed- management approach to be implemented. Mapping, on the other hand, is not as concerned about missing small infestations. Instead, it focuses on documenting the extent and location of general fronts of weed spread, and management tends to be reactive.

Satellite imagery from Landsat Thematic Mapper (TM) was used in conjunction with digital elevation models (DEMs) to identify habitat susceptible to invasion by a particular noxious weed. This project also generated a literature review of noxious weeds and remote sensing that is available as a separate document from RSAC (Lachowski, Varner, & Maus, 1996).

STUDY AREA

Four noxious weeds that have significant, isolated populations near the boundary of the Frank Church River of No Return Wilderness (Wilderness) in central Idaho were selected for this project. The weeds and their locations are listed on the following page and shown in Figure 1.

- Yellow starthistle (near White Bird, ID)
- Rush skeletonweed (near Lowman, ID)
- Leafy spurge (near Carmen, ID)
- Spotted knapweed (near North Fork, ID)

PHENOLOGICAL CHARACTERISTICS

Yellow Starthistle (*Centaurea solstitialis* L.) is a spiny species introduced from Europe which presently infests most of the West. The plant is an aggressive winter annual that varies in height from six inches to two feet. Winter annuals are very competitive for available soil nutrients and water.

The plant germinates in the fall and winters over in a rosette stage, actively growing and establishing an extensive root system. This characteristic gives yellow starthistle an advantage over more desirable perennial vegetation. Due to prolific seed production and vegetative competitiveness, the plant establishes sites easily and then is difficult to eradicate. This weed is visually distinct in late spring when the plant stems have bolted (one-plus feet tall). The blue-green hue of this stage contrasts with other vegetation. Yellow starthistle is also visually distinct in late fall through the winter when the standing dead stems appear gray with white cottony tufts at their ends after seed dispersal. The stem skeletons can persist for long periods of time (D. Sorensen, personal communication, February 7, 1997).

Spotted Knapweed (*Centaurea maculosa* Lam.) was introduced from Eurasia as a contaminant of alfalfa and clover and ranks as the number one weed problem on rangeland in western Montana as well as other states (Whitson et al., 1996). It is a biennial or short-lived perennial ranging from one to three feet tall. Spotted knapweed is very aggressive and establishes itself on beaches and roadsides and in other disturbed areas with little and/or stressed vegetation. While spotted knapweed is found on most aspects and moisture gradients, it becomes established faster and persists longer in moist sites. Beginning in June, this species becomes visually distinct from surrounding vegetation by its pink-purple flower. In late fall, winter, and early spring, standing dead gray stems make the plant visible (D. Sorensen, personal communication, February 7, 1997).

Rush Skeletonweed (*Chondrilla juncea* L.) is an introduced Eurasian species which presently infests several million acres in Idaho, Oregon, Washington, and California (Whitson et al., 1996). It is an aggressive perennial ranging from one to four feet in height. Leaves forming a basal rosette fade as the flower stems develop. Plants generally inhabit well-drained, coarse-textured

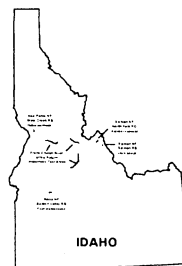


Figure 1. Location of study area.

soils. Rush skeletonweed becomes visually distinct from surrounding vegetation in late fall when the flower stem husk turns blackish, in early spring when the basal rosette forms prior to “green up” of surrounding vegetation, and in the fall when it turns red orange (D. Sorensen, personal communication, February 7, 1997).

Leafy Spurge (*Euphorbia esula* L.) is native to Eurasia and was brought into the United States as a seed impurity that now infests approximately 2.5 million acres (Whitson et al., 1996). It is a perennial that grows up to three feet tall and reproduces from vigorous rootstock and seed. Leafy spurge is primarily found in untilled noncropland habitats such as pastures, rangelands, woodlands, roadsides, and waste areas. The plant tends to occupy sites with a high sand content. Once leafy spurge is established, there does not seem to be any topographic limit to the invasion of new areas. Leafy spurge is visually distinct from surrounding vegetation in early spring when it is one of the first plants to emerge, in midsummer when the flower is in full bloom, and in the fall when it turns rust orange in contrast to other lighter green and/or straw-colored vegetation (D. Sorensen, personal communication, February 7, 1997).

SUSCEPTIBILITY MODELING

Many noxious weeds have specific site requirements which can be modeled to identify habitat susceptible to invasion and possibly the degree of susceptibility (low, moderate, or high). The cost of data acquisition can be reduced or better focused by knowing where and how susceptible a habitat is to invasion. A model of the method of mapping susceptible habitat is shown in Figure 2. Layers such as cover type, elevation, aspect, and slope, stored in a geographic information system (GIS), can be used to model susceptible habitat. Other data layers in a more complex model include soils, recreation features like trails and campsites, and wind patterns.

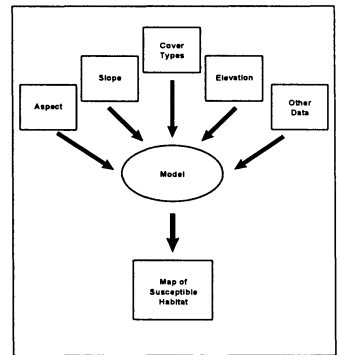


Figure 2. A conceptual model for creating a map of susceptible habitat.

The cover-type layer was developed from an August 10, 1992, Landsat TM image (30 meter pixel resolution). This data was procured for the entire country by the USDA Forest Service Interregional Ecosystem Management Coordination Group (IREMCG). A pilot area, encompassing four 7.5- minute quadrangles (Pungo Mountain, CO; Norton Ridge, CO; Little Soldier Mountain, CO; and Sliderock Ridge, CO) in the Wilderness, was clipped out of the full Landsat TM scene, and an unsupervised classification (see Maus

et al., 1995) was run to produce a 30-class map. The 30-class unsupervised classification ultimately reduced to a cover-type map containing 6 classes, comprised of water (W), bare rock (B), sandbars (SB), trees (T), shrubs (S), and grasslands (G). Aspect, slope, and elevation data layers for the same area were derived from the DEMs.

A conceptual model of susceptible habitat for rush skeletonweed is presented as an example. The parameters (Table 1) are for demonstration purposes only and are not intended to produce an actual map of habitat susceptible to invasion by rush skeletonweed.

Table 1
Parameters for Susceptible Habitat Model

<u>Layer/Susceptibility</u>	<u>Cover Type</u>	<u>Aspect</u>	<u>Slope</u>	<u>Elevation</u>
High	SB, S, G	SE, S, SW	0-15%	below 2000m
Moderate	n/a	E, W	16-30%	2001-2500m
Low/Not Susceptible	W, B, T	NE, N, NW	above 31%	above 2500m

This model produced several combinations of layers and susceptibility that had to be evaluated and reclassified into categories of highly susceptible, susceptible, or not susceptible. The first evaluation criteria was cover type. All combinations containing cover types with a code of low/not susceptible were placed in the not susceptible category. The remaining combinations were reclassified into categories (high, moderate, low/not susceptible) based on aspect. An aspect in the moderate category was moved to high if slope or elevation was also high but was not moved to low in the

reverse situation. Figure 3 shows each of the data layers and the output from the model. The lighter areas represent habitat susceptible to invasion, while the darker areas are habitat highly susceptible to invasion by rush skeletonweed. Figure 4 shows the areas on the Landsat TM image of the pilot area that are either susceptible or highly susceptible to invasion. This information can be used during flight planning to focus data collection efforts.

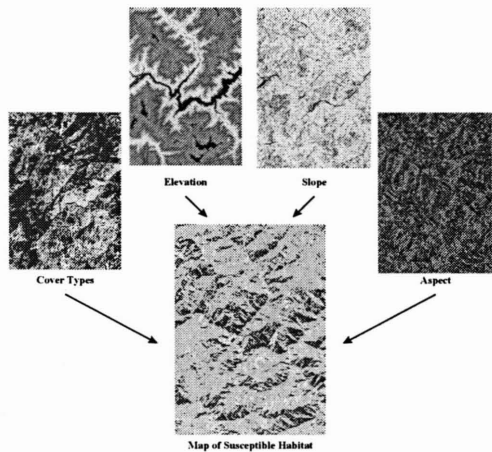


Figure 3. The data layers used and the output from the model representing susceptible habitat.

FLIGHT PLANNING

Previous experience indicated that CIR digital camera imagery acquired at 0.5 and 1.0 meter spatial resolution would provide good information for the desired minimum mapping unit of one-half acre. The spatial resolution requirements resulted in flying altitudes of 3,500 and 7,000 feet above ground level (AGL). A flight line approximately five miles along a river corridor was selected in each of the infested areas. In the case of leafy spurge, the flight line was shorter and laid out along two drainages instead of a river corridor. An additional three flight lines were laid out in the Wilderness interior, where infestation levels of the various noxious weeds are unknown. The Wilderness flight lines ran a total of approximately 100 stream miles along the Middle Fork and main Salmon River. Each flight line was flown three times, once down the middle of the stream corridor at 7,000 feet AGL, acquiring data on both sides of the river, and the second and third times at 3,500 feet AGL on each side of the river.

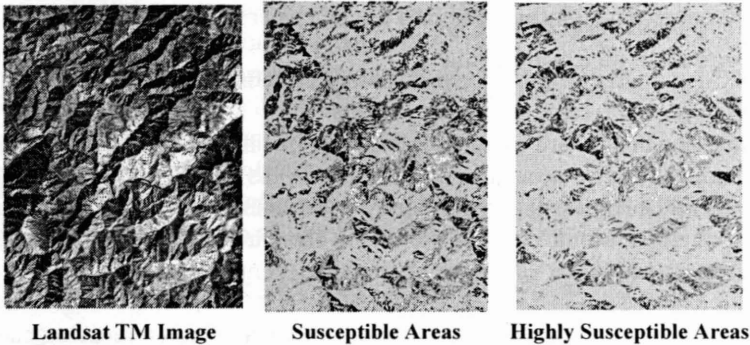


Figure 4. A Landsat Thematic Mapper image (left) and the image showing areas that are susceptible (middle) and highly susceptible (right) to invasion.

DATA ACQUISITION

The week of July 22, 1996, was selected for the aerial data collection because all four of the noxious weeds were expected to be in an early to midstage of flowering. The phenological stage of each weed was assessed in the field prior to aerial data collection. Yellow starthistle, assessed during the week of July 14, ranged from vegetative to seeds dispersed with most plants in a postflowering stage. Rush skeletonweed, also assessed during the week of July 14, was predominantly in a bud (preflower) stage. Leafy spurge and spotted knapweed, both assessed on July 22, were in a seeds developed to dispersed

stage (postflower) and vegetative to bud stage with some flowering, respectively.

A cluster of instruments, including a CIR digital camera, a multispectral video camera, a 70-mm camera, and a natural-color video camera, was mounted in the aircraft. A total of almost 400 stream miles were flown, resulting in almost 2,000 digital camera images, 450 frames of 70-mm photography, and four hours of multispectral video imagery on SVHS tape.

The Kodak DCS 420 Color Infrared Digital Camera records imagery to a CCD array that replaces the back on a Nikon N90 camera body (Remote Sensing Applications Center [RSAC], 1996). Images are stored in a compressed digital format on a PC card. The swath width of the digital camera imagery is approximately one mile at 7,000 feet AGL and a half mile at 3,500 feet AGL. This camera was interfaced with a Trimble GPS unit. Latitude and longitude as well as other information from the GPS unit were recorded with each digital camera image file. This information was later used to create a flight-line map showing the approximate location of each digital camera image.

The Xybak multispectral video camera has a rotating filter wheel that allows six images to be captured nearly simultaneously in six different wavelengths. The images are captured in blue, green, and two red bands in the visible spectrum, and two near infrared bands on SVHS videotape. The swath width of the multispectral imagery is slightly wider than for the digital camera imagery. A small Panasonic natural-color video camera used for navigation recorded imagery on SVHS videotape. A caption generator recorded time, latitude, and longitude information received from an Ashtech GPS unit directly onto the navigation videotape, which was used as a locational reference for the other imagery.

Stereo pair and triplet frames of 70-mm natural color Hasselblad photography were acquired randomly along the flight lines. Oblique stereo pairs of 35-mm slides were also acquired at random from the aircraft window.

INTERPRETATION OF IMAGERY

The blue-green hue of the yellow starthistle was apparent on the ground during a site visit in late June but had faded by the time the aerial data were collected in July. However, areas dominated by the gray stem skeletons were apparent on the Hasselblad photography, though they were easily confused with rock outcrops, especially on steeper slopes (Figure 5). In this part of the Salmon River Canyon, large infestations of yellow starthistle appeared to be restricted to southern aspects. The CIR digital camera imagery was interpreted by resource specialists familiar with the area. Polygons delineating areas thought to be

noxious weed infestations were digitized on the screen and saved as a coverage. Field validation revealed that the interpretation was too conservative, encompassing robust weed population centers but missing many low-density areas.

Rush skeletonweed was also much more evident on the ground during the late June site visit due to its height, vegetative form, and standing dead stems. Infestations were not very apparent on any of the imagery. Field validation of the interpreted CIR digital camera imagery showed that once again the interpretation was too conservative and southern aspects were a controlling factor in rush skeletonweed infestation. Though disappointing, these results were not unexpected (Figure 6). The thin, stalky stems of this plant do not make it a good remote sensing target.

Another attempt at detecting rush skeletonweed should be made in the late fall or early winter prior to snow cover, when the husk is blackish.

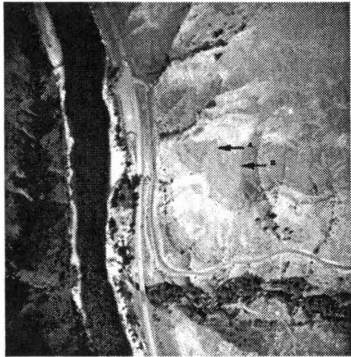


Figure 5. Yellow starthistle as seen on 70-mm Hasselblad photography. Location A is an infestation. Location B is a ridgetop with exposed rock.



Figure 6. A digital camera image of the rush skeletonweed site. The larger polygons represent onscreen digitizing and the smaller polygons with percentages in them represent the field validation. Percentages describe the extent of infestation.

As with the yellow starthistle, the gray standing dead plant stems were the visual key to areas infested with spotted knapweed on the Hasselblad photography and to a lesser degree on the CIR digital camera imagery and certain band combinations of the Xybion multispectral imagery. New infestations and those without the skeletal stems were not distinct from other green vegetation. There does not appear to be an aspect component to this particular infestation.

Though it was in a postflowering stage, the quantity and size of the persistent petal-like bracts and its bushy form made leafy spurge the easiest of the weeds to see on all of the aerial images (Figure 7). It was equally easy to see on both natural color and color infrared imagery. Moist drainage bottoms appeared to be the initial point of infestation, and then, once established, leafy spurge climbed side slopes with no apparent aspect preference. In this particular setting, leafy spurge is also apparent in early fall as burnt orange in contrast to the surrounding straw-colored vegetation.

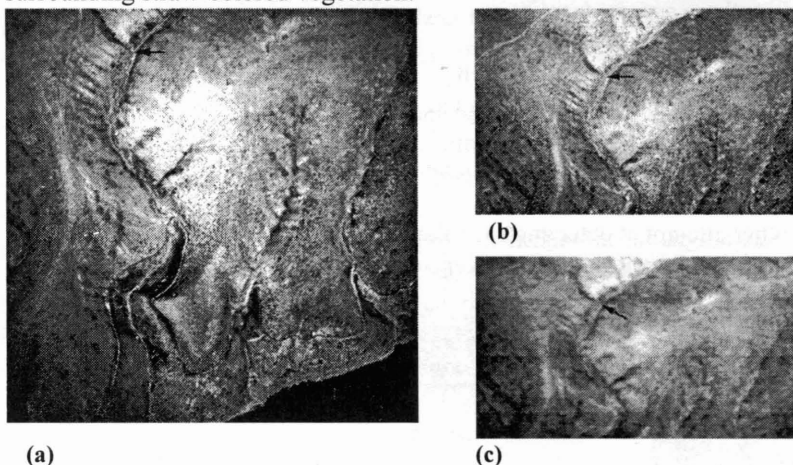


Figure 7. Leafy spurge as seen on (a) 70-mm Hasselblad photography, (b) digital camera image, and (c) Xybion image displaying bands 6, 4, and 3.

RESULTS

The ability to detect small infestations of the target weeds was complicated by both site and plant characteristics. The density of infestations varied greatly with site quality. Yellow starthistle grew in low-productive, shallow soils. The density of starthistle was sparse even though it was the dominant plant. At these sites it was difficult to separate the target weed from rock and bare soil. Yellow starthistle also varied from a robust multibranched plant to a single stem. Its

reflective qualities were significantly different on sites dominated by the single-stemmed form. On many sites the sparse, single-stemmed infestations could not be separated from bare rock and soil.

The complexity of the canyon and mountainous landscapes was also a confounding factor. The interaction of slope, aspect, elevation, soils, site quality, and associated plant species made consistent interpretation difficult. Deep shadows in steep canyon areas and bright reflection from sandy soils along the rivers were also factors interfering with consistent interpretation. Infestations were most evident in the 70-mm natural color photographs, which had the finest ground resolution and largest footprint (area covered by a single frame) of all the aerial data acquired at the same altitude. However, the cost and time required for film processing, locating the photos on a map, and converting this imagery to a digital format for use in a GIS can be prohibitive.

Infestations were less apparent on images from the color infrared digital camera, which has a coarser resolution and a smaller footprint. The main advantages of this type of imagery are (1) it is acquired in a digital format, (2) it has general location information from a GPS that is linked to each image, and (3) the images can be viewed immediately after they are acquired. Digital camera technology is still evolving. Chip size, storage capacity, and recycle time limit the resolution and footprint size of this type of imagery. However, these limiting factors have improved dramatically in the past year and will continue to be refined as the technology matures. In the meantime, the resolution of 70-mm photography can be obtained with the digital camera by flying at a lower altitude and/or changing the focal length of the camera lens. These strategies will increase the number of frames of digital imagery but should remain cost effective for a typical project area.

SUMMARY AND RECOMMENDATIONS

Data at various levels of resolution that cover small to large areas at a specific point in time can be provided by remote sensing. This comprehensive perspective is useful in the management planning process to assess the current situation and answer questions like “Where do we have a problem with noxious weeds?”, “How extensive is the noxious-weed infestation?”, “Where is the infestation likely to spread?”, and “What areas are not likely to be affected?” It can also help establish a baseline for monitoring, predicting future change, or planning and evaluating the effectiveness of weed control programs. Remote sensing data, when georeferenced, can be stored and manipulated in a geospatial database such as a GIS that, when combined with other data, becomes information. For example, the land-cover layer from Landsat TM, when combined with soil, aspect, slope, and elevation, can be used to model

susceptible habitat. The same data can also predict storm runoff or potential soil loss.

Coarse resolution satellite imagery like Landsat TM provides broad areal coverage (approximately eight million acres per scene). This imagery can be analyzed into classes representing general vegetation or land cover patterns, which can then be incorporated into susceptible habitat models. Information from the model and plant physiology will determine areas to be flown, aircraft altitude, and optimum focal length of the camera lens.

Aerial data collection should occur during the period when the reflective characteristics of the plant are most distinct. The length of the optimum phenological window will vary among species and sites. This factor adds complexity to a project where more than one weed is targeted for identification. In addition the varying slopes, aspects, and elevations of this particular study area made detection of small infestations, as well as early identification of any invading weeds, difficult with this set of aerial data. The ability to detect small or early infestations of noxious weeds may be improved in more homogeneous landscapes.

The timing of data acquisition was the most critical factor in distinguishing noxious weeds from surrounding cover and heavily influenced the results of this study. The study tested the feasibility of detecting and mapping four noxious weeds at one time, during peak flowering. However, a single flight period did not capture the optimum phenology for all the plants. Of the four noxious weeds selected for the project, infestations of leafy spurge were the easiest to detect at an early stage because it was studied during an optimal time frame. Leafy spurge was apparent on all the aerial imagery. Gray skeletal plant stems were the visual key for both spotted knapweed and yellow starthistle infestations. In mid-July, small or sparsely populated infestations of these two weeds were difficult to identify consistently from the imagery. The detection of new infestations may be improved by determining if unique phenological characteristics can be seen from the air. Rush skeletonweed, which could not be identified at all from the imagery due to its physiological characteristics, may be detectable using this strategy.

Yellow starthistle, spotted knapweed, and rush skeletonweed may have distinctive signatures outside the peak flowering period. Future projects should consider aerial data collection during autumn or early winter for rush skeletonweed and early summer or late winter for yellow starthistle. These unique phenological time periods may yield better detection and mapping results.

Note: The indication of firms, corporations, or trade names in this paper is for the convenience of the reader and does not constitute an official endorsement of any product or service by the USDA Forest Service.

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